APPENDIX A
Manned Space-Flight Capabilities

INTRODUCTION

This paper presents systems descriptions of NASA manned space-flight capabilities in a program extending from the early 1970's to 1980 and beyond. For the relatively near-term Apollo applications program (AAP), these capabilities are well on their way toward realization. Toward the mid-1970's commitments are less definite, but specific plans are being laid which could culminate in a space station as early as 1975 and in some kind of lunar scientific station in the latter half of the 1970's. As part of the space station system, a low-cost transportation shuttle development is planned. Whether or not these systems come along as projected here will depend largely on decisions made at the national level as to the pace and scope of the program. Nevertheless, the systems described in this paper are representative of our thinking, and many of them, or systems of similar capability, are highly desirable and can be expected to come into being sooner or later.

APOLLO APPLICATIONS PROGRAM

The Apollo applications program, which follows Apollo, was conceived to make optimum use of the manned space-flight capability developed during Gemini and Apollo. The program takes advantage of the space vehicles, facilities, and organizations as they are made available by the Apollo program. Flights will begin in the early 1970's, and the technology provided will be important to future, long-duration space station design and development. The AAP missions use five Saturn IB launches, three manned and two unmanned, to perform three interrelated missions beginning in the latter half of 1971 and ending in 1972.

The Saturn I workshop mission (AAP-1/AAP-2) uses the empty hydrogen tank of the S-IVB stage (after its use as a launch vehicle stage) as the nucleus of an embryonic space station. In orbit, the workshop consists of the modified stage plus two modules: an airlock and a multiple-docking adapter. The airlock module provides access to the stage interior, to the docking adapter, to space for extravehicular activity, and to space for experiments requiring it; it also provides environmental control, power, communications, and control functions. The multiple docking adapter provides docking accommodations for an Apollo command and service module and the Apollo Telescope Mount, which is brought up in the third mission; experiments and several habitability systems are stored here during launch. Workshop electrical power is supplied by solar panels and batteries.

The workshop, with its auxiliary equipment, is launched unmanned. The three-man crew with its logistic support will rendezvous with the Saturn I workshop in an Apollo command and service module (CM and SM) modified to extend mission duration and to interface properly with the workshop. Following venting of the tank, the crew will complete outfitting of the workshop for living and working, and initiate the experimental phase of the mission. The mission duration will be open-ended up to 28 days.

This Saturn I workshop mission is designed to provide space and facilities for a broad spectrum of experiments and provide a foundation of basic information essential to the design and development of follow-on space station systems. It emphasizes medical and habitability experiments, but also supports a number of science and technology experiments.

The first workshop revisit mission (AAP-3A) uses a single Saturn IB launch of the modified three-man command and service module to rendezvous and dock with the Saturn I workshop set up in the previous mission. This mission is the first flight test of the concept of reusing a habitable space structure after several months of uninhabited operation in orbit. The planned duration of up to 56 days is the next step in the progressive extension of mission length to test and evaluate systematically the ability of both men and spacecraft to function effectively over long periods of time in space. For this reason the primary in-flight experiment emphasis will be on the medical area. This will probably be the first mission in which a medical doctor is a member of the crew.

The solar astronomy mission (AAP-3/AAP-4) uses the Saturn I workshop as a base of operations for the manned Apollo Telescope Mount (ATM) solar observatory. One Saturn IB launches a modified three-man CM and SM configured for up to a 56-day mission; a second Saturn IB launches the unmanned lunar module/Apollo Telescope Mount (LM/ATM) with its payload of solar instruments. After the CM/SM rendezvous and dock with the Saturn I workshop, the crew reactivates the workshop.

The LM/ATM then accomplishes rendezvous, unmanned, with the workshop and is docked to the docking adapter under the control of an astronaut in the workshop. This will be the first time we have performed an unmanned rendezvous, a technique which we expect will be of great importance in the future. This technique will be used to bring subsatellites into a space station, service them, and then send them back out–a function which may become one of the major uses of space stations. The unmanned rendezvous technique will also be used in the future to bring payloads up to space stations and return payloads to Earth, as in the LM/ATM mission.

The LM/ATM uses a modified ascent stage of the Apollo lunar module plus an Apollo Telescope Mount. The ATM consists of a structural rack carrying the solar astronomy instruments, a coarse-pointing control system, including control moment gyros which can also maintain the orientation of the entire workshop ATM assembly, a fine-pointing gimbal system to aim the solar telescopes to an accuracy of ±2–1/2 arc-seconds, the thermal control system, and the array of solar cells and the power conditioning and distribution system which power the ATM. The solar instruments payload consists of two X-ray telescopes, a combination spectro-heliograph and spectrograph operating in the extreme ultraviolet, a scanning spectrometer in the extreme ultraviolet, and a white-light coronagraph. The ascent stage serves as the experiment control station during ATM operations, provides propulsion and flight control for rendezvous and docking the ATM to the workshop, and serves as the base for extravehicular activity to retrieve film from the solar telescopes. The complete workshop/ATM cluster is illustrated in figure A-1.

This mission will give us about 2 months of solar observation time. Should the Saturn I workshop not be available for reuse, contingency plans have been made to fly the solar astronomy mission decoupled from the Saturn I workshop orbital assembly.

The Apollo applications program will provide criteria important

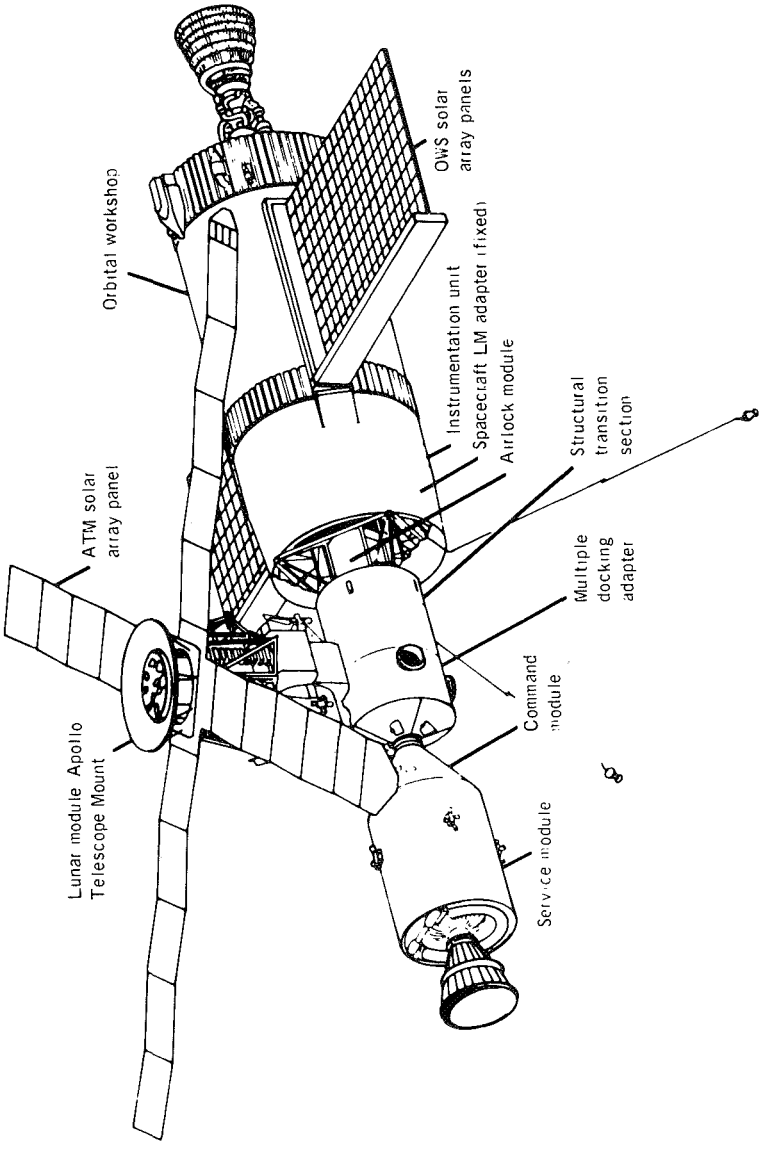

Figure A-1.–Apollo applications program cluster.

to future space station programs in the following areas: physiological effects of long-duration zero-gravity, crew performance, habitability requirements, work station requirements, extravehicular capabilities, vehicle engineering and system qualification, mission operations, and experiment operations.

SPACE STATION

NASA will shortly embark on the formal definition of a space station program, with flight occurring as early as 1975. This is a significantly more advanced concept than the Saturn I workshop in the Apollo applications program and will possess a high degree of mission and operational flexibility as well as adaptability to a broad band of schedule and funding possibilities. The goal of this program is the establishment of a multipurpose, general-usage laboratory for a variety of disciplines including astronomy, Earth sciences and applications, industrial processes, physics, life sciences, and advanced technology. The present view is that the best way to approach this capability is not to try to design the ultimate space station now, but rather to design those parts of the space station, which we call modules, that we are sure will be needed. Basically there will be three kinds of modules–utility modules, living modules, and experiment modules. The living modules are sent up first, and later, as the development of the experiments is finished, an experiment module is sent up and latched onto the living quarters. The experiment modules would be laboratory-type modules designed with the instrumentation and flexibility to carry out a range of experiments within a given discipline, such as cosmic ray experiments, much like ground laboratories. In this way these experiment modules could be used over a long period of time for different observations, and consequently achieve economical operation through a high degree of utilization. The module diameter should be about 22 feet, and the weight will be in the range of 40 000 to 100 000 pounds. A certain number of these modules could be combined and launched at the same time on a single Saturn V, or they could be launched separately on Saturn IB's, or intermediate launch vehicles. The exact size and weight for which these modules should be designed will be better defined in studies to be carried out this year.

The space station will be designed for as much as 10 years of continuous operation. This will be achieved by fundamentally

highly reliable subsystem designs plus provisions for maintenance and repair, expendables replenishment, and refurbishment and replacement. Crew productivity over this period of time will be assured by rotation at 3- to 6-month intervals and by bringing up new experiment packages and modules as they become available and can be accommodated by the station workload. Productivity will be further enhanced by the use of a comprehensive onboard data system for checkout, experiments system monitoring, communications, and other functions, thereby freeing the crew's human capabilities, as much as possible, for research and experimentation.

The station is initially planned for a crew size of 12 men. Enlarging the station for larger crew sizes can be accomplished by modular techniques, the same as for accommodating changing mission requirements. The internal payload support volume will be at least 10 000 cubic feet.

The environmental control and life-support system for the station will provide a two-gas, nitrogen-oxygen atmosphere. It will provide a shirt-sleeve environment and maintain regulated suit loops for extravehicular-activity (EVA) payload support. The oxygen loop will be open, at least initially; however, the water loop will be closed except for fecal water.

Electrical power will probably be supplied by solar panel arrays, but incorporation of a nuclear electrical power supply may be desirable for some applications. The power to be provided for the initial module may run as high as 30 kilowatts and may go as high as 100 kilowatts as additional modules are added to the station.

A relatively high-accuracy attitude stabilization system will be incorporated for both Earth-centered and celestial-inertial orientations, according to the nature of the experiment program requirements. Systems of horizon scanners, star trackers, and rate gyros and conventional thrusters can furnish activation forces adequate for most station and experiment requirements ($\sim 1/2^{\circ}$). Experiment stability requirements beyond the basic station capability will be provided by the particular experiment package.

The space station and its launch system will be compatible with operation of the space station in orbits of 200- to 300-nautical-mile altitudes and any orbit plane ranging from polar to equatorial. The 200- to 300-nautical-mile altitude range represents a compromise between the requirements of Earth-viewing experiments for low altitudes and the penalties associated with atmospheric drag. The

space station will also be adaptable in some form to operation in an Earth-synchronous orbit. Ultimately, we may wish to operate multiple space stations, the orbit altitude and inclination of each being selected in accordance with the special purposes of that station. We may also develop new technological uses for space stations, such as using them as staging points, to which propellants could be carried from Earth by a low-cost logistics vehicle, for deep-space missions. Another potentially important use of space stations in our future programs is for providing a support facility for checking out, servicing, and repairing unmanned satellites.

In the process of the space station program, manned systems will become operational for the purpose of fulfilling scientific, technological, and space applications objectives. The space station program will also (1) extend the present knowledge of the long-term biomedical and behavioral characteristics of man in space; (2) continue the development of systems and technology required to maximize the utility of man in space; and (3) develop practical solutions for establishing, operating, and maintaining long-duration orbital stations by evaluation of actual flight experience.

LOW-COST TRANSPORTATION

A low-cost transportation system development will be implemented in parallel with the space station. Logistics systems for personnel rotation, expendables resupply, and experiments and experiment-module delivery represent a major share of the manned Earth-orbiting space station flight program costs. Planning studies conducted by both DOD and NASA, past and present, unanimously underscore the importance of, and the need for, a more operationally effective and cost-efficient manned, round-trip, Earth-orbital transportation system. Figure A-2 illustrates the economic significance of logistics costs in the space station program. Based upon current Saturn or Titan class launch vehicles and Apollo or Gemini type vehicles for the logistics spacecraft, logistics cost could represent about 40 percent of the total program cost for the first year, and about two-thirds of the recurring cost for each additional year of operation. The viability and success of long-duration space station flight programs are therefore directly related to the availability of a more cost-effective and versatile round-trip transportation system. NASA has studied a wide range of concepts

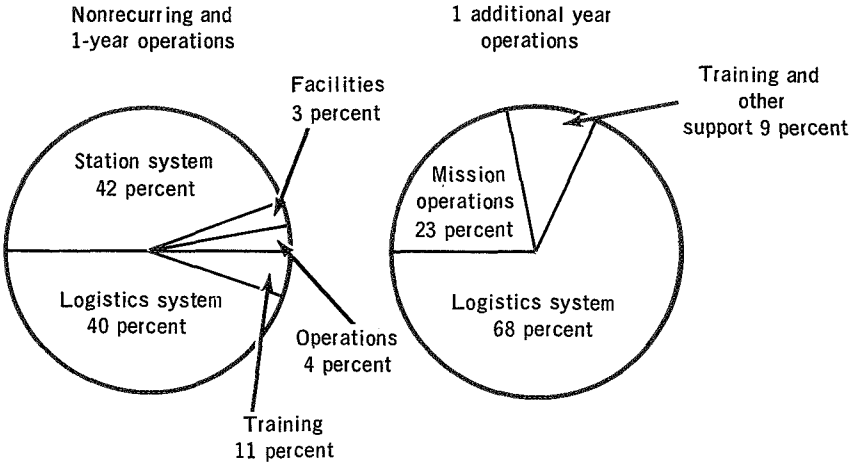

Figure A-2.—Economic significance of logistics to the space station program.

for new logistics vehicles, including conventional expendable systems, new high lift/drag (L/D) spacecraft, and reusable systems.

Conventional expendable launch vehicles with new ballistic spacecraft can achieve small steps towards cost reductions with correspondingly small technological risks and investment requirements. In view of the relatively high launch rates anticipated, this approach does not offer sufficient potential for cost reduction.

Another concept would utilize a low-to-medium L/D advanced logistics spacecraft which could be reused and an expendable launch vehicle designed with emphasis on operations economy and safety. This concept includes consideration of solid- and liquid-boost stages of simplified design. The spacecraft would be large, providing ample crew size and internal cargo capability, and have an advanced landing system utilizing a decoupled mode for terminal flight. For maximum economy, the guidance system and orbital propulsion systems would be integral with the spacecraft, so that these relatively expensive systems would also be reused. The configuration and operational mode would be selected to provide cost effectiveness in terms of checkout, turnaround, recovery, and reuse. The extent of savings achievable in this approach is limited by the fact that significant and expensive elements of structure and propulsion would be thrown away on each flight.

The most advanced concept in the spectrum is a new, integrated, logistic space vehicle system that would utilize more advanced technologies and techniques, such as medium-to-high L/D, requiring one and one-half stages to orbit, and consisting of a reusable, integral launch-and-reentry vehicle with low-cost, high mass-fraction, expendable propellant tanks attached to the sides of the vehicle. The recoverable vehicle would contain all of the systems required for boost into orbit (including the booster engines), mission accomplishment in orbit, and reentry. It would be a vertical-takeoff, horizontal-landing vehicle which would contain all of the costly hardware elements of the system, thus permitting the recovery and reuse of these elements. The boost propellant tankage would not be recovered, because it is one of the least costly elements of the system and one of the most penalizing to recover in terms of added weight to the reentry vehicle.

This system is characterized by extensive technological demands and investment costs, but promises a great reduction in manned-system operational costs. It would utilize a number of technological improvements, which are within our capabilities to develop, in order to achieve routine and economical airplanelike operations. It would have advanced heat protection and structural systems which would minimize the cost of refurbishment and maintenance associated with each flight, onboard checkout to minimize the ground crew required for preflight and postflight operations, high-pressure hydrogen/oxygen rocket engines to minimize propellant usage and throwaway tank weight, and advanced landing techniques such as variable geometry and/or jet engines to allow horizontal landing at speeds typical of conventional airplanes. Although this concept presents more of a technical challenge than the others, its design should be started soon, in view of its potential for greatly lowering operational costs.

LUNAR EXPLORATION

Continued lunar exploration will parallel the Apollo applications and space station programs. The first successful manned lunar landing will be followed by several repeat missions modified in only minor ways. Following these missions, the Apollo systems will be improved, and the first half of the 1970's will see increased staytime on the lunar surface, improved astronaut mobility, extended range of traverses, establishment of lunar-wide geo-

physical networks, and the conduct of photographic and remote-sensing surveys from lunar orbit.

As with the Apollo applications program, the lunar program in the early 1970's will make maximum utilization of Apollo hardware. The duration of the lunar module on the lunar surface will be extended from about 36 hours to 3 days. A small lunar flying unit could be carried along which would provide a high degree of mobility, up to 10 kilometers from the lunar module, allowing the astronaut to visit special features, deploy equipment, return samples, or rescue a second crewmember. Preliminary studies indicate that such a flying unit would weigh nearly 200 pounds and use residual propellants from the lunar module descent stage. It would carry the pilot with his personal equipment and 400 pounds of payload, or an additional crewmember. The possibility of using flying vehicles for more extensive transportation on the lunar surface is also being studied.

For missions later than the 1972-73 time period, NASA is studying the development of a roving vehicle that can be operated either manned or unmanned. During manned operation, the rover will conduct loop sorties up to 10 kilometers from the spacecraft, with a round-trip distance of 30 kilometers and a speed up to 15 kilometers per hour. In the automated mode, the rover will make traverses of approximately 1000 kilometers at an average speed of 1 to 2 kilometers per hour. It will be capable of operating in rugged terrain to investigate regions of high scientific interest. The vehicle will make scientific measurements along the traverse, deploy automated scientific stations, and collect lunar samples. Vehicle power will come from a combination of solar panels, batteries, and a radioisotope thermoelectric generator.

The internal structure and energy budget of the Moon will be investigated primarily by seismic networks that will require simultaneous operation of widespread, long-lived stations. Measurements of heat flow and lunar gases will also be conducted with these arrays. The Advanced Apollo Lunar Surface Experiments Package (ALSEP) will comprise a central station with standard experiment interface for power and data, and a number of pallets carrying modular surface experiments. Power will be supplied by a radioisotope thermoelectric generator. A remote geophysical monitor and a science station would be similar to the ALSEP, but contain smaller and more compact experiment systems.

Orbital measurements are essential for lunar-wide understanding and geodetic control. Consideration is being given to the use of instrumentation in the manned, orbiting, command and service module after the lunar module is dispatched to the lunar surface. Orbital surveys would be conducted using the techniques of metric photography, radar, altimetry and tracking, high-resolution photography, and spectroscopy.

Determination of the interaction of the Moon and the space environment includes disturbances of solar wind plasma (shock front and shadow zone), penetration of the solar-wind magnetic field into the interior of the Moon, and nuclear reactions induced in the lunar surface material by cosmic radiation. A "clean" orbiter, free from magnetic and radiation interference, can be deployed in lunar orbit as a subsatellite from the command and service module, or launched directly from Earth, like the anchored Interplanetary Monitoring Platform (IMP), Explorer XXXV.

During the mid-1970's, further extensions of Apollo-derivative systems could be used in increasingly ambitious missions. For example, modifications to the Apollo hardware could extend lunar surface staytime to 2 weeks and could lead to substantially increased scientific payload and astronaut mobility. A 7- to 14-day lunar module taxi would be employed to deliver the two crewmen, along with equipment, to the lunar surface for field geology investigations and return them to an orbiting 20-day command and service module. During their staytime on the Moon, the crew would live in a shelter that may be environmentally attached to the lunar module taxi, or provided by a previously landed lunar payload module. The latter vehicle would be delivered by a manned flight to lunar orbit and landed unmanned at a site of scientific interest. The payload would typically consist of a lunar roving vehicle, two-man shelter, small laboratory, advanced ALSEP, and lunar flying units.

A further step in lunar capability would involve use of at least three men on the surface for periods in excess of a lunar day. These missions would be used for extended exploration or for site revisit. A new three-man lunar module would land three astronauts on the lunar surface and return them and scientific data to lunar orbit for rendezvous with the command and service module. A 90-day, quiescent command and service module could deliver a three-man crew to lunar orbit, and would wait up to 90 days in quiescent mode for crew return. After reactivation by the crew, it would then return them to Earth.

An unmanned lunar module truck would deliver as much as 10 000 pounds to the lunar surface. A suitable shelter providing convenient accommodation and life support for the crew would weigh about 2000 pounds, including fuel cells, radiators, and breathing oxygen. The astronauts would use the standard Apollo lunar orbit rendezvous mode, except that the entire three-man crew would transfer to the three-man lunar module. After landing, the three-man lunar module would either remain dormant, waiting to return the crew, or a following lunar module would be used for crew rotation and site revisit. Weight additions required to provide for quiescent standby (meteoroid protection, electrical power, radiator, etc.) will require propulsion-system upratings.

A lunar base of some kind could be available in the late 1970's or early 1980's. Such a semipermanent base or scientific observatory would be capable of supporting 6 to 12 men continuously for a year or more. The base system would be modular and comprised of sequentially launched cargo landers carrying shelter modules, power (nuclear) modules, and life-support and communications modules. Mobility devices, operating with attachments, would be available to provide at least partial burying of the modules.

Cargo delivery could be based on an uprated Saturn V (60-percent uprate), which would launch new braking and landing stages into a translunar trajectory. The braking stage would remain in lunar orbit and the landing stage would then descend to the surface with a 50 000-pound payload. Personnel delivery would also be based on use of the same launch vehicle, with braking and landing stages carrying a six-man modified Apollo command module and ascent stage for Earth return. During the period of lunar stay, the personnel carrier could be placed in a dormant, standby condition.

After the Apollo landing has been accomplished, the next phase of lunar exploration will gain sufficient knowledge of the Moon to determine the nature and direction of additional exploration or exploitation. Considerable progress toward resolving questions of the composition, structure, and processes of the Moon's surface and interior, and the history of events by which the Moon arrived at its present configuration can be expected. Comparative study of the Earth-Moon system will have advanced our understanding of our own planet, and the entire solar system. Results of exploration missions will determine how the Moon's unique environment can be

exploited to utilize it as a space platform for astronomy, research, and applications.